Metallic or semiconducting liquid silicon under swift heavy ion (SHI) irradiation

Sjoerd Roorda (Université de Montréal) and Gabrielle Long (ANL)

Irradiation of solids with swift heavy ions (SHI) leads to ultra-rapid and localized excitations of the electronic system not unlike those encountered under femto-second laser irradiation. It is widely believed that the electronic excitation very rapidly transfers to the ions in the solid, leading to melting and rapid solidification. In the ion beam community, this behavior of ion impact sites is known as a thermal spike (Toulemonde, *Radiation Effects and Defects in Solids*). *n.b.:* This thermal spike is not to be confused with the thermal spike which can occur near the end of the ion's trajectory, and which is due to a dense cascade of nuclear collisions.

For a target consisting of pure amorphous silicon, it has been argued that the liquid phase which forms during such a SHI induced thermal spike is in fact a semiconducting phase of much lower density than the normally occurring metallic, 6-fold coordinated, liquid Si (Hedler, *Nature Materials*). However, the evidence for this statement is post mortem only, very indirect, and unlikely in view of the phase diagram of silicon (Sinke, *JMR*). We propose a measurement which may provide proof that the liquid phase involved is indeed the regular metallic liquid phase.

Our proposed measurement relies on the observed fact that a first-order phase transition separates amorphous from liquid silicon, but not amorphous silicon from its semiconducting liquid phase, if indeed such a phase exists and can be attained. A first order phase boundary that travels through the material will phase-segregate impurities. Indeed, by this mechanism, pulsed ruby laser annealing was recognized to involve regular melting. We propose to irradiate with SHI a piece of amorphous silicon that contains a small (0.1 %) concentration of metallic impurities (Ag), atomically dispersed. When the ions pass through, narrow cylinders would melt and subsequently solidify. The solidification would proceed radially inward, leaving a cylinder denuded of Ag impurities except for a highly Ag-enriched central axis. Such a structure should be observable by grazing incidence small angle scattering. If we find evidence for Ag segregation towards the central axis of each of the ion impact cylinders, then we have very convincing evidence for the presence of the regular liquid silicon phase.

The immediate impact of a successful measurement would be twofold: first of all, it would disprove the earlier claim, published in *Nature Materials,* of the observation of 'glassy silicon'. Second, it would reopen the question of how amorphous materials deform under SHI, a phenomenon known as hammering or anisotropic growth.

References:

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